Attachment 1 to Item 10.3.1.

Draft Macdonald River, Colo River, Webbs Creek and Greens Creek Flood Study - Report.

Date of meeting: 18 February 2025
Location: Council Chambers
Time: 6:30pm

Macdonald River, Colo River, Webbs Creek & Greens Creek

Flood Study

DRAFT

Hawkesbury City Council | RR-02-1382 | February 2025

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Cover photo – photo of the Colo River near the Upper Colo Gauge, June 2020.

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Report Structure

The reporting for the Macdonald River, Colo River, Webbs Creek & Greens Creek Flood Study and Floodplain Risk Management Study and Plan has been presented in four key documents:

- **Flood Study** – establishes the flood behaviour and risk within the study area.
- **The Flood Risk Management Study** – details the assessments undertaken as part of the study.
- **The Flood Risk Management Plan** – presents an implementation strategy for Council to prioritise floodplain management options.
- **Map Compendium** – a set of A3 maps as referenced in the Flood Study, Flood Risk Management Study and Flood Risk Management Plan.

Foreword

The primary objective of the New South Wales (NSW) Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.

Through the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) and the NSW State Emergency Service (SES), the NSW Government provides specialist technical assistance to local government on all flooding, flood risk management, flood emergency management and land-use planning matters.

The *NSW Flood Risk Management Manual* (NSW Government, 2023a) is provided to assist councils to meet their obligations through the preparation and implementation of flood risk management plans, through a staged process. **Figure F1**, taken from this manual, documents the process for plan preparation, implementation and review.

The *NSW Flood Risk Management Manual* (NSW Government, 2023a) is consistent with Australian Emergency Management Handbook 7: *Managing the floodplain: best practice in flood risk management in Australia* (AEM Handbook 7) (AIDR 2017).

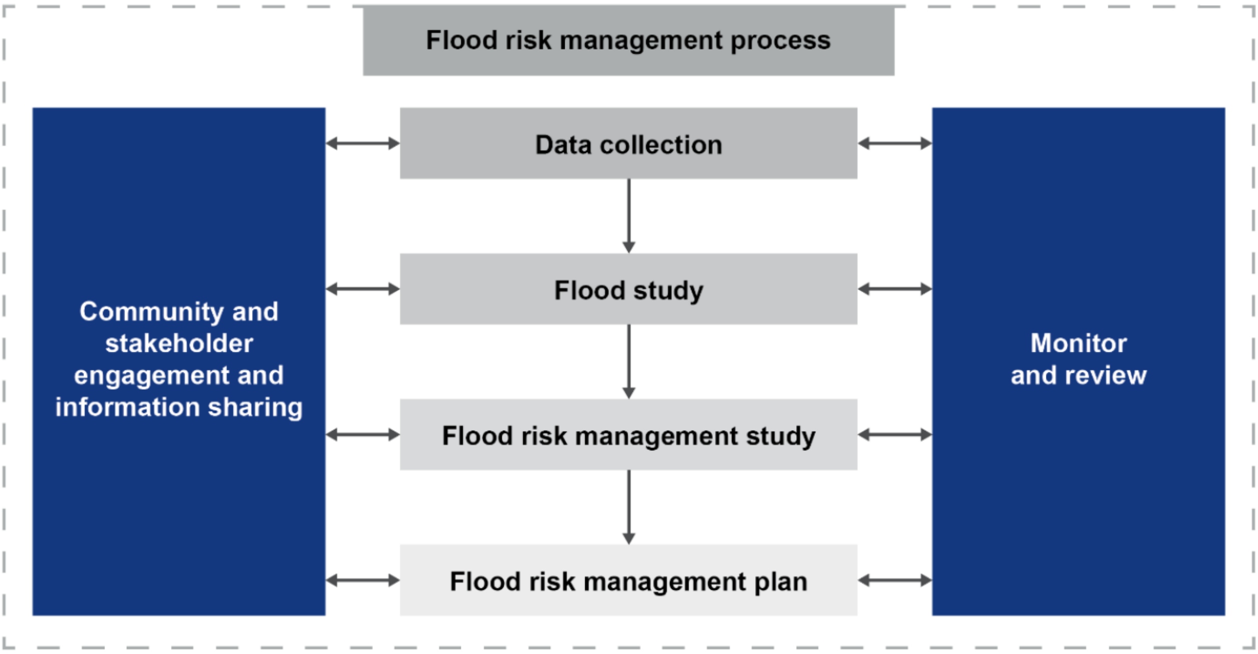

Figure F1. The Flood Risk Management Process (source: NSW Government, 2023a)

Executive Summary

The Macdonald River, Colo River, Webbs Creek and Greens Creek Flood Study has been prepared for Hawkesbury City Council (Council) to refine the understanding of flood risk in the study area.

Flooding is a known risk within the study area, affecting private and public property and access during and after flood events. The flooding of key crossings also restricts the response of emergency personnel during emergencies. Each catchment is also affected by backwater flooding from the Hawkesbury River, which can also exacerbate the isolation risk.

Study Area and Scope

The study area includes four catchments: the Macdonald River, Colo River, Webbs Creek, and Greens Creek. Each catchment discharges into the Hawkesbury River. The catchments within the study area are varied, with the Colo River covering 4,640 km², the Macdonald River 1,845 km², Webbs Creek 363 km², and Greens Creek 10 km².

The topography throughout the study area is predominantly steep, with the river flowing through valleys that are semi confined by sandstone. Due to the semi-confined valley topography, flood levels, particularly in the Colo and MacDonald Rivers, can reach significant heights.

This report is a flood study, which is a comprehensive technical investigation of existing flood behaviour. The overall objective of this study is to improve Council's understanding of flood behaviour and impacts, and better inform management of flood risk in the study area in consideration of the available information, and relevant standards and guidelines. The project will also assist Council with planning for future development and will provide flood information to the SES to enable them to progress their emergency management planning for the region

Engagement

Stakeholder engagement was undertaken throughout the flood study. This involved:

- Engaging agency and industry stakeholders to obtain details of historical flooding, survey data and other relevant data sets.
- Initial community engagement has been undertaken through the mail-out of a letter and questionnaire to residents in the study area. The letter also provided a link to a Your-Hawkesbury-Your-Say project page and an online copy of the survey. A community drop-in session was also held. The purpose of the initial community engagement was to raise awareness of the study and flood risk in the catchment, obtain observations and experiences of recent flooding to assist in model calibration, and understand community experiencing due and after flood evets. The drop in sessions also provided an opportunity to seek community input on potential flood mitigation measures to be investigated in the Flood Risk Management Study and Plan.

Hydrological and Hydraulic Modelling

Flood modelling has been undertaken using a combination of hydrological and hydraulic models. Hydrological modelling was undertaken for the study area using WBNM, and catchment flooding was modelled in TUFLOW. Both models extend to the outlet of the Hawkesbury River.

Historical flood data was available from rainfall, stream gauges and flood marks. Sufficient data was available for the Colo and Macdonald catchments to allow a calibration of both the hydrological and hydraulic models against historical events from 1978, 2020, March 2022 and July 2022.

The hydrological and hydraulic models were analysed for the Probable Maximum Flood (PMF), 1 in 2000 AEP, 1 in 1000 AEP, 1 in 500 AEP, 1 in 200 AEP , 1% AEP, 2% AEP, 10% AEP and 20% AEP events. The design events are based on ARR2019 methods. For the Macdonald and Colo Rivers, the design events have also been calibrated using flood frequency analysis

Design events were modelling in using 2D hydraulic models. The incised catchments limit the variation in flood extent across events, but the topography results in significant increases in flood depths especially for rarer events. PMF presents flood levels significantly higher than the 1% AEP event—up to 10 metres in some cases—accompanied by extreme depths and velocities. While rare, these conditions necessitate careful consideration in flood risk management to address the potential impacts of catastrophic flooding.

Hydraulic Model Sensitivity

The sensitivity of the hydraulic model to roughness, inflows, downstream boundary conditions, blockage and climate change were assessed in the TUFLOW model.

The results showed that the Macdonald and Colo models are more sensitive to changes in roughness and the predicted impacts of climate change than the Webbs Creek and Green Creek models. This was due to the significantly higher flows within the confined Colo and Macdonald Rivers valleys.

Each model was relatively sensitive to changes in the downstream boundary level, particularly in the lower 1-5 km of each watercourse. For Greens Creek in particular, backwater flooding from the Hawkesbury River is the dominate flooding mechanism.

The models were insensitive to blockage assumptions. Minor changes of less than 10 cm occurred in the vicinity of some bridges. This was due to the capacity of the crossing being negligible compared to the capacity of the river channel at the peak of the flood events.

Conclusion

This report provides a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust flood risk management study and plan.

The data developed as part of the study provides a better understanding of the flood behaviour and risks across the full range of flood events. It involved consideration of the local flood history, available flood data, and the development of hydrologic and hydraulic models that are calibrated and verified against historic flood events.

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Map Compendium

Map Number	Description	Map Number	Description
RG-00-001-1	Calibration July 2022 Colo River	RG-00-306	1 in 200 AEP Hazard
RG-00-001-2	Calibration July 2022 MacDonald River	RG-00-307	1 in 500 AEP Hazard
RG-00-002-1	Calibration March 2022 Colo River	RG-00-308	1 in 1000 AEP Hazard
RG-00-002-2	Calibration March 2022 MacDonald River	RG-00-309	1 in 2000 Hazard
RG-00-003-1	Calibration February 2020 Colo River	RG-00-310	PMF Hazard
RG-00-003-2	Calibration February 2020 MacDonald River		
RG-00-004-1	Calibration March 1978 Colo River	RG-00-401	1% AEP Flood Function
RG-00-004-2	Calibration March 1978 MacDonald River	RG-00-402	1 in 200 AEP (0.5% chance per year) Flood Function
		RG-00-403	1 in 500 AEP (0.2% chance per year) Flood Function
RG-00-101	20% AEP Peak Depth and Level	RG-00-404	PMF Flood Function
RG-00-102	10% AEP Peak Depth and Level		
RG-00-103	5% AEP Peak Depth and Level	RG-00-501	20% AEP High Blockage Sensitivity
RG-00-104	2% AEP Peak Depth and Level	RG-00-502	1% AEP High Blockage Sensitivity
RG-00-105	1% AEP Peak Depth and Level	RG-00-503	20% AEP Low Blockage Sensitivity
RG-00-106	1 in 200 AEP Peak Depth and Level	RG-00-504	1% AEP Low Blockage Sensitivity
RG-00-107	1 in 500 AEP) Peak Depth and Level	RG-00-505	20% AEP High Roughness Sensitivity
RG-00-108	1 in 1000 AEP Peak Depth and Level	RG-00-506	1% AEP High Roughness Sensitivity
RG-00-109	1 in 2000 AEP Peak Depth and Level	RG-00-507	20% AEP Low Roughness Sensitivity
RG-00-110	PMF Peak Depth and Level	RG-00-508	1% AEP Low Roughness Sensitivity
RG-00-201	20% AEP Peak Velocity	RG-00-601	1% AEP Climate Change 2050 SSP3
RG-00-202	10% AEP Peak Velocity	RG-00-602	1% AEP Climate Change 2100 SSP3
RG-00-203	5% AEP Peak Velocity		
RG-00-204	2% AEP Peak Velocity	RG-00-701	Building Flooding
RG-00-205	1% AEP Peak Velocity	RG-00-702	Road Crossings
RG-00-206	1 in 200 AEP Velocity	RG-00-703	Infrastructure and Facilities
RG-00-207	1 in 500 AEP Velocity		
RG-00-208	1 in 1000 AEP Velocity	RG-00-801	Zoning
RG-00-209	1 in 2000 AEP Velocity	RG-00-802	Flood Planning Area
RG-00-210	PMF Peak Velocity	RG-00-803	Flood Planning Constraint Categories
RG-00-301	20% AEP Peak Hazard	RG-00-901	Emergency Management Classification of Communities
RG-00-302	10% AEP Peak Hazard		
RG-00-303	5% AEP Peak Hazard		
RG-00-304	2% AEP Peak Hazard		
RG-00-305	1% AEP Peak Hazard		

Glossary

The following glossary was adapted from the NSW Flood Risk Management Manual (NSW Government, 2023a).

Term	Description	Context for use/additional information
Annual exceedance probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage	AEP is generally the preferred terminology. ARI is the historical way of describing a flood event; for example, a 1% AEP flood has a 1% or 1 in 100 chance of being reached or exceeded in any given year
Australian Height Datum (AHD)	A common national surface level datum often used as a referenced level for ground, floor and flood levels	0.0m AHD corresponds approximately to mean sea level
Average recurrence interval (ARI)	The long-term average number of years between the occurrence of a flood equal to or larger in size than the selected event	ARI is the historical way of describing a flood event. AEP is generally the preferred terminology; for example a 100-year ARI flood that has 1 in 100 chance of being reached or exceeded in any given year. It is equivalent to a 1% AEP flood
Catchment	The area of land draining to a specific location	It includes the catchment of the primary waterway as well as any tributary streams and flowpaths
Defined flood event (DFE)	The flood event selected as a general standard for the management of flooding to development	Used to define the flood planning levels
Design flood	Design floods are hypothetical floods used for planning and floodplain management investigations. They are based on having a probability of occurrence specified as Annual Exceedance Probability (AEP) expressed as a percentage.	The design flood may be considered the flood mitigation standard for works or planning. For example, a levee may be designed to exclude a 2% AEP flood, which means that floods rarer than this may breech the structure and impact upon the protected area. In this case, the 2% AEP flood would not equate to the crest level of the levee, because this generally has a freeboard allowance, but it may be the level of the spillway to allow for controlled levee overtopping
Development	May be treated differently depending on the following categorisation: **infill development**: the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under current land zoning **new development:** development of a completely different nature to that associated with the former landuse (e.g. the urban subdivision of a previously rural area) **redevelopment**: rebuilding in an area (e.g. as urban areas age, it may become	New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power Redevelopment generally does not require either rezoning or major extensions to urban services

Term	Description	Context for use/additional information
	necessary to demolish and reconstruct buildings on a relatively large scale)	
Flood	A natural phenomenon that occurs when water covers land that is normally dry. It may result from coastal inundation (excluding tsunamis) or catchment flooding, or a combination of both	Flooding results from relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flowpaths associated with major drainage, and/or oceanic inundation resulting from superelevated ocean level
Flood awareness	An appreciation of the likely effects of flooding, and a knowledge of the relevant flood warning, response and evacuation procedures facilitating prompt and effective community response to a flood threat	In communities with a low degree of flood awareness, flood warnings may be ignored or misunderstood, and residents confused about what they should do, when to evacuate, what to take with them and where to go
Flood education	Seeks to provide information to raise awareness of flooding so as to enable individuals to understand how to manage themselves and their property in response to flood warnings	It can support a state of flood readiness
Flood evacuation	The movement of people from a place of danger to a place of relative safety, and their eventual return	People are usually evacuated to areas outside of flood prone land with access to adequate community support Livestock may be relocated to areas outside of the influence of flooding
Flood fringe areas	That part of the flood extents for the event remaining after the flood function areas of floodway and flood storage areas have been defined	
Flood function	The flood related functions of floodways, flood storage and flood fringe within the floodplain	Flood function is equivalent to hydraulic categorisation
Flood hazard	A flood that has the potential to cause harm or conditions with the potential to result in loss of life, injury and economic loss	The degree of hazard varies with the severity of flooding and is affected by flood behaviour (extent, depth, velocity, isolation, etc.)
Flood impact and risk assessment	A study to assess flood behaviour, constraints and risk, understand off-site flood impacts on property and the community resulting from the development, and flood risks to the development and its users	These studies are generally undertaken for development and are to be prepared by a suitably qualified engineer experienced in hydrological and hydraulic analysis for flood risk management
Flood plan (local or state)	A subplan of an emergency plan that deals specifically with flooding; they can exist at state, zone and local levels	The NSW Government develops flood plans as a legislative responsibility to determine how best to respond to floods. These community-based plans describe the risk to the community, outline agency roles and responsibilities, the agreed community emergency response strategy and how floods will be managed. The relevant plan

Term	Description	Context for use/additional information
		within the study area is the Hawkesbury-Nepean Valley Sub-Plan.
Flood planning area (FPA)	The combination of the flood level from the DFE and freeboard selected for FRM purposes	Different FPLs may apply to different types of development. Determining the FPL for typical residential development should generally start with a DFE of the 1% AEP flood plus an appropriate freeboard (typically 0.5 metres). This assists in determining the FPA
Flood planning levels (FPLs)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also consider the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plans.	The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
Flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).	
Flood prone land	Land susceptible to flooding by the PMF event	Flood prone land is also known as the floodplain, flood liable land and flood affected land
Flood storage areas	Areas of the floodplain that are outside floodways which generally provide for temporary storage of floodwaters during the passage of a flood and where flood behaviour is sensitive to changes that impact on temporary storage of water during a flood.	See also flood function, floodways and flood fringe areas
Floodplain	Land susceptible to flooding by the PMF event.	See the definition of flood prone land
Floodways	Areas of the floodplain which generally convey a significant discharge of water during floods and are sensitive to changes that impact flow conveyance. They often align with naturally defined channels.	See also flood function, floodways and flood fringe areas Floodways are sometimes known as flow conveyance areas

Term	Description	Context for use/additional information
Freeboard	A factor of safety typically used in relation to the setting of minimum floor levels or levee crest levels	Freeboard aims to provide reasonable certainty that the risk exposure selected in deciding on a specific event for development controls or mitigation works is achieved. Freeboards for development controls and mitigation works will differ. In addition, freeboards for development control may vary with the type of flooding and with the type of development
Gauging height	The height of a flood level at a particular water level gauge site related to a specified datum	The datum may or may not be the AHD
Hazard	A source of potential harm or conditions that may result in loss of life, injury and economic loss due to flooding	
Hydraulics	The study of water flow in waterways and flow paths; in particular, the evaluation of flow parameters such as water level and velocity	
Hydrology	The study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods	
Merit-based approach	Weighs social, economic, ecological and cultural impacts of land-use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and wellbeing of the state's rivers and floodplains	The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk, which are formulated into council plans, policy, and environmental planning instruments. At a site-specific level, it involves consideration of the merits of a development consistent with council LEPs, DCPs and local FRM policies, and consistent with FRM plans
Probability	A statistical measure of the expected chance of a flood	For example AEP
Probable maximum flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation (PMP), and where applicable, snow melt, coupled with the worst flood producing catchment conditions	This is equivalent to the probable maximum precipitation flood in Australian Rainfall and Runoff (ARR). The PMF in ARR is used for estimating dam design floods
Risk	'The effect of uncertainty on objectives' (ISO 2018)	See also flood risk. Note 4 of the definition in ISO31000:2018 also states that 'risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood'

Term	Description	Context for use/additional information
Stage	Equivalent to water level; measured with reference to a specified datum	Measurement may relate to AHD, a local datum or a local water level gauge
Velocity	The speed of floodwaters, measured in metres per second (m/s)	

Abbreviations

1D	One Dimensional
2D	Two Dimensional
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
ARR87	Australian Rainfall and Runoff 1987
ARR2019	Australian Rainfall and Runoff 2019
BoM	Bureau of Meteorology
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DCP	Development Control Plan
DEM	Digital Elevation Model
DPE	Department of Planning and Environment
DPIE	Department of Planning, Industry and Environment
FPL	Flood Planning Level
FRMP	Flood Risk Management Plan
FRMS	Flood Risk Management Study
FPRMSP	Flood Risk Management Study & Plan
ha	Hectare
IFD	Intensity Frequency Duration
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
LiDAR	Light Detection and Ranging
m	metre
m^2	Square metres
m^3	Cubic metres
mAHD	metres to Australian Height Datum
mm	millimetres
m/s	metres per second
NSW	New South Wales
OEH	Office of Environment and Heritage (NSW)
OEM	Office of Emergency Management
PMF	Probable Maximum Flood
RMS	Roads and Maritime Services
SES	State Emergency Service (NSW)
SSP	Shared Socioeconomic Pathway

1 Introduction

The Combined Macdonald River, Colo River, Webbs Creek and Greens Creek Flood Study and Flood Risk Management Study and Plan (FRMSP) has been prepared for the Hawkesbury City Council (Council) in accordance with the New South Wales (NSW) Flood Prone Land Policy and the Flood Risk Management Manual (NSW Government, 2023a) and its supporting guidelines.

The Flood Study is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust FRMSP.

The outcome of the project is a FRMSP that identifies and evaluates potential measures to reduce the flood risk and associated damages in Macdonald River, Colo River, Webbs Creek & Greens Creek catchments. The options considered in the FRMSP will include an assessment of flood warning, evacuation and isolation within the study area. The FRMSP will also be used to inform strategic planning and development assessment throughout the study area.

1.1 Project Objectives

The overall objective of this study is to improve the understanding of flood behaviour and impacts to inform the management of flood risk in the study area.

The project incorporates three key components:

- **The Flood Study.** The flood study defines flood behaviour to better inform flood risk management. The flood study considers available information, previous studies and relevant standards and guidelines including Australian Rainfall and Runoff (2019) and the latest climate change guidance.
- **Flood Risk Management Study.** The FRMS will evaluate a range of measures (including emergency response, property modification and flood modification measures) to address the flood risk and inform the development of a Floodplain Risk Management Plan.
- **Flood Risk Management Plan.** The FRMP will provide a strategic level plan for Council to manage the flood risk in the study areas moving into the future.

The overall project will provide an understanding of, and information on, flood behaviour and associated risk and may inform:

- relevant government information systems;
- government and strategic decision makers on flood risk;
- the community and key stakeholders on flood risk;
- emergency management planning for existing and future development;
- flood risk management planning for existing and future development;
- selection of practical, feasible and economic measures for treatment of risk;
- decisions on insurance pricing;
- development of a floodplain risk management plan; and
- development of a prioritised implementation strategy.

2 Catchment Description

The study area incorporates four key catchments:

- Macdonald River (**Section 2.1**);
- Colo River (**Section 2.2**);
- Webbs Creek (**Section 2.3**); and,
- Greens Creek (**Section 2.4**).

An overview of the catchments and corresponding study areas is provided in **Figure 2-1**. Each catchment drains generally in a south easterly direction into the Hawkesbury River and is described in further detail below. The study areas cover the lower reaches of each catchment and encompass most of the developed and rural land relevant to the Hawkesbury City Council local government area (LGA).

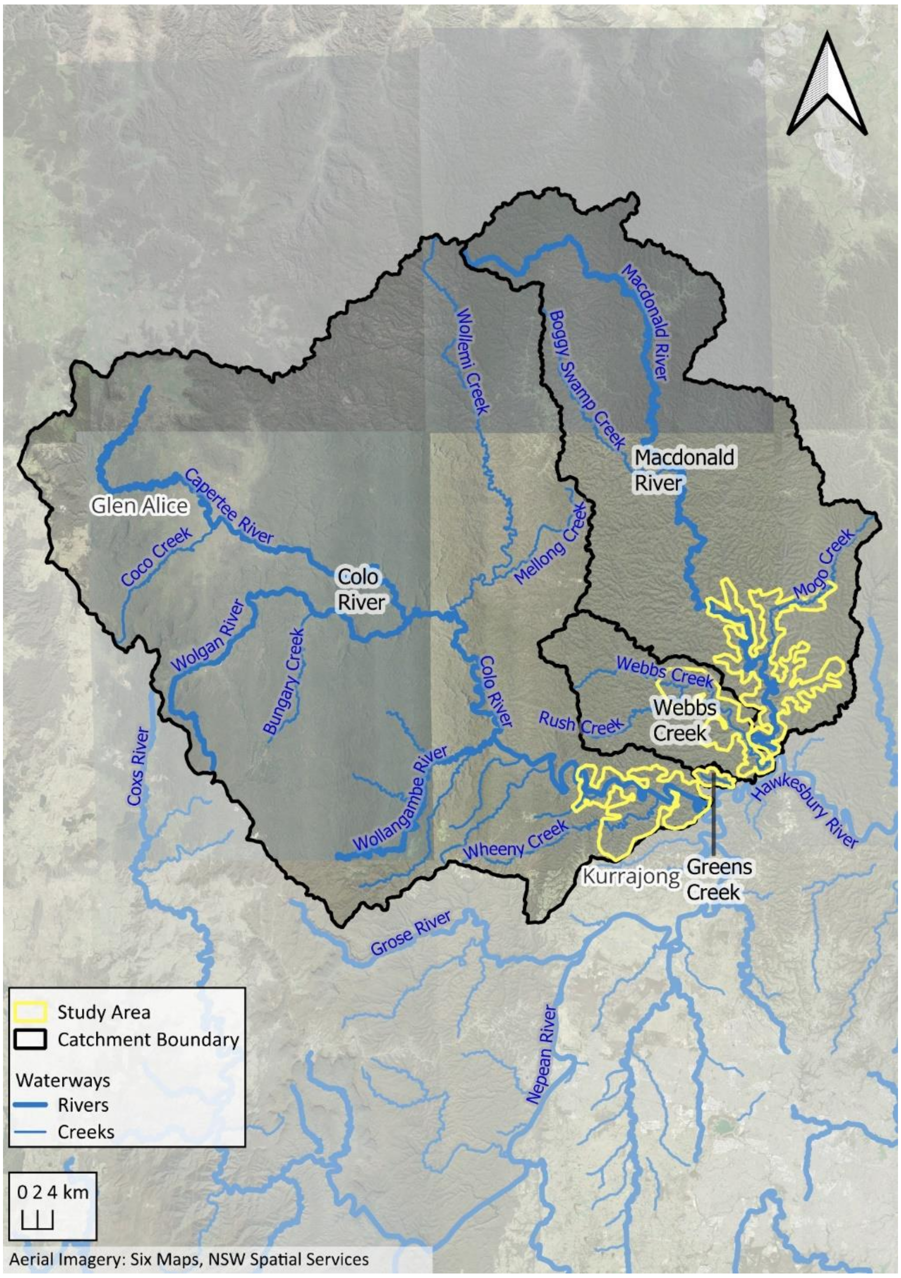

Figure 2-1 Study area

2.1 Macdonald River

The Macdonald River is a tributary of the Hawkesbury River and drains a catchment area of approximately 1,845 km^2 and a length of approximately 150 km. The Macdonald River channel has a dynamic nature that is geomorphologically very active. The catchment consists of steeply vegetated slopes up to elevations of around 800 m. The upper portions of the catchment consist predominantly of natural bushland. Downstream of the Mogo Creek confluence, the Macdonald River floodplain is constrained within a steep valley that is typically 300-500 m wide. The majority of development within the catchment consists of scattered free-standing dwellings located on rural acreages, typically zoned C4 – Environmental Living. St Albans is the only village within the catchment and has a population of around 300 people. The density of development increases in the downstream reaches of the valley. The highest concentration of residential development is located approximately 1-2km upstream of the Hawkesbury River junction, along the eastern side of the Macdonald River floodplain.

Figure 2-2 Macdonald River at Higher Macdonald (18 February 2022)

Flooding within the valley is primarily a consequence of surface runoff generated in the upper reaches and from local catchments. The lower reaches of the Macdonald River are also affected by backwater effects from the Hawkesbury River. Significant recent flooding occurred in 2020, 2021, March 2022 and July 2022.

There is also an established history of flooding with significant events known to have occurred in 1978, 1964, 1949 and as far back as 1867.

2.2 Colo River

The Colo River begins at the confluence of the Wolgan River and the Capertee Rivers, north of Lithgow. The river flows eastwards and then south through a deep gorge in the northern Blue Mountains and ultimately flows into the Hawkesbury River at Lower Portland. The Colo River is approximately 97 km in length and has a catchment area of 4,640 km^2. A majority of the catchment is undeveloped. Within the study area, development consisting of scattered free-standing dwellings is located on rural acreages on land zoned C4 – Environmental Living. The study area also supports a significant ecotourism and outdoor education sector that at times supports large groups of tourists and school groups.

Figure 2-3 Colo River at Upper Colo Bridge (17 February 2022)

Flood behaviour in the Colo River catchment is comparable to the Macdonald River. Flooding results from surface runoff generated in the upper reaches and from local catchments. The lower reaches of the Colo River are also affected by backwater effects from the Hawkesbury River. The catchment has experienced significant recent flooding with major flooding recorded in 2020, 2021, March 2022 and July 2022. The March 2022 event was the largest recently recorded event.

2.3 Webbs Creek

Webbs Creek is approximately 40 km in length and has a catchment area of 363 km2. Webbs Creek flows generally south-east before reaching its confluence with the Hawkesbury River, around 500m upstream from the Webbs Creek Ferry crossing The lower reaches of Webbs Creek are tidal and subject to backwater effects from the Hawkesbury River when the Hawkesbury is in flood.

The majority of development within the Webbs Creek catchment is found in the lower portions of the catchment. The developed area consists of scattered free-standing dwellings located on land zoned C4 – Environmental Living. The remainder of the catchment is heavily vegetated bushland with steep slopes. The catchment also supports a significant ecotourism sector including outdoor retreats. There are no towns or villages in the catchment. There is limited information relating to historic flooding in the catchment.

Figure 2-4 Webbs Creek, looking upstream from Chaseling Road North Bridge (17 February 2022)

2.4 Greens Creek

Greens Creek is a small (6 km long) perennial watercourse located at Lower Portland, with a catchment area of 10 km2. The creek flows in general in the south-east direction to join the Hawkesbury River. Flooding in the catchment is dominated by backwater from the Hawkesbury River.

Development in the catchment includes low density rural residential properties within land zoned C4 – Environmental Living.

Figure 2-5 Greens Creek, looking upstream from Greens Road (17 February 2022)

3 Data Review

3.1 Previous Studies and Reports

Table 3-1 outlines the historic reports compiled for the study area and a summary of the relevance to this study. The studies were provided by Council or sourced from publicly available sources including the NSW SES flood data portal. A significant number of the studies have focussed on flooding behaviour and flood risk along the Hawkesbury-Nepean River including backwater effects along the Colo and Macdonald Rivers. The Lower Macdonald River Flood Study (Webb, McKeown & Associates, 2004) is the most recent study to specifically examine Macdonald River flooding. No previous studies have solely focussed on the flood behaviour of the Colo River, Greens Creek or Webbs Creek.

Table 3-1 Previous studies

Document	Relevance to Study
Lower Macdonald River Flood Study (Webb, McKeown & Associates, 2004)	The Lower Macdonald River Flood Study was prepared by Webb McKeown & Associates in 2004. A Watershed Bounded Network Model (WBNM) hydrologic model was established to represent the entire catchment draining to the Hawkesbury River. A MIKE-11 hydraulic model was created to represent the Lower Macdonald River downstream of the confluence with Womerah Creek. The lower reaches of Wrights Creek were also included in the hydraulic model. The hydrologic and hydraulic models were calibrated making use of available historical data to ensure that they reasonably simulated recorded historical floods. The models were calibrated to the March 1978 flood and verified against the August 1990 event. A flood frequency analysis was undertaken on the streamflow estimates obtained from the gauge located on the Macdonald River at St Albans. The adopted set of design flows were used to define inflow hydrographs to the hydraulic model. The calibration parameters from this report have informed the hydrological calibration for the current study. Comparisons are also made with the flood levels from this study (See **Section 6.2**).
Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024)	An investigation of flood behaviour for the Hawkesbury-Nepean River between Bents Basin and Brooklyn was undertaken using a WBNM hydrologic model and a TUFLOW hydraulic model, underpinned by a Monte Carlo framework. Further, a detailed investigation was undertaken on the joint probability of Colo and Macdonald River flooding with Hawkesbury River flooding. The Macdonald River, Colo River, Webbs Creek and Greens Creek are impacted by backwater flooding from the Hawkesbury-Nepean River. The Hawkesbury-Nepean River Flood Study has informed the downstream boundary conditions for this current study. Hydrologic and hydraulic model elements have been used in this investigation.
Hawkesbury Nepean Valley Regional Flood Study (WMA Water, 2019)	This flood study includes an investigation of flood behaviour for the Hawkesbury-Nepean River between Bents Basin and Brooklyn, using a RORB hydrologic model, RUBICON hydraulic model, Monte Carlo framework, and flood frequency analysis. This study has subsequently been updated in the Rhelm CSS (2024) study.

Document	Relevance to Study
Hawkesbury Floodplain Risk Management Study and Plan (Bewsher, 2012)	This FRMSP includes an investigation and assessment of flood behaviour and floodplain management options along the Hawksbury River within the Hawkesbury City Council LGA. The Bewsher (2012) study focusses on the Hawksbury River floodplain between Yarramundi and Sackville and is therefore upstream of the current study area. The Bewsher (2012) study identifies high priority flood measures related to community education, evacuation and land use planning that the current FRMS can build on for the Colo River, Macdonald River, Webbs Creek and Greens Creek catchments.
Hawkesbury Floodplain Risk Management Study and Plan Draft (WMA Water, 2025)	This study provides an update to Bewsher (2012) and is informed by the results of the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024). The study was recently publicly exhibited and includes a range of flood mitigation options. The study also recommended the flood planning level be increased to the 200 year AEP to consider the impacts of climate change.

3.2 Survey Data

3.2.1 LiDAR

Several aerial survey data sets are available for the study area. These data sets are summarised in **Table 3-2**.

Table 3-2 Available LiDAR data and reported accuracy

Year	Source	Formats	Average Point Separation (m)	Horizontal Accuracy (m)	Vertical Accuracy (m)
2021	ELVIS website*	1 m DEM, Point cloud	Not reported	0.8 @ 95% confidence interval	0.3 @ 95% confidence interval
2010	ELVIS website*	30 m DEM,	Not reported	Not reported	Not reported

* ELVIS – Elevation and Depth – Foundation Spatial Data website (https://elevation.fsdf.org.au/).

The 2021 LiDAR is the most recent dataset and was used to define the floodplain ground levels.

Where floor level survey is not available, the ground levels represented by the 2021 LiDAR set were used to estimate floor levels for the surrounding urban development.

3.2.2 Existing Ground Survey

No ground survey was available within the study area.

3.2.3 Floor Level Survey

No floor level survey was available within the study area.

3.2.4 Additional Survey

Additional channel and structure survey was collected in August 2023 by BCE Ppatial to fill data gaps and provide representative channel cross sections to inform the hydraulic model. The survey details are provided in **Appendix A.**

3.3 Hydrologic Data

3.3.1 Rainfall Data

A number of agencies collect rainfall data within the study area, including:

- Bureau of Meteorology (BoM);
- Sydney Water Corporation (Sydney Water);
- Manly Hydraulics Laboratory (MHL); and
- WaterNSW.

As part of the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024), rainfall data was compiled and processed from these agencies for the rainfall gauges throughout the catchment, as well as areas adjacent to the catchment. This included data sourced from the BoM rainfall database.

Within the study area, there are 47 daily rainfall gauges operated by the BoM. There are eight sub daily gauges within the study area (discussed further in **Section 4.2**). **Figure 3-1** shows the location of the BoM daily rainfall gauges within the study area surrounding areas. The gauges are distributed in the upper and lower Macdonald and Colo River catchments. There are large areas within both catchments where there are no rainfall gauges. It should also be noted that not all gauges were operational for all historic events. There are no gauges in the Greens Creek or Webbs Creek catchments. For calibration and validation purposes, the processed rainfall data from Rhelm CSS (2024) was used. The processed data features the prioritisation of gauges based on proximity, data quality and length of record.

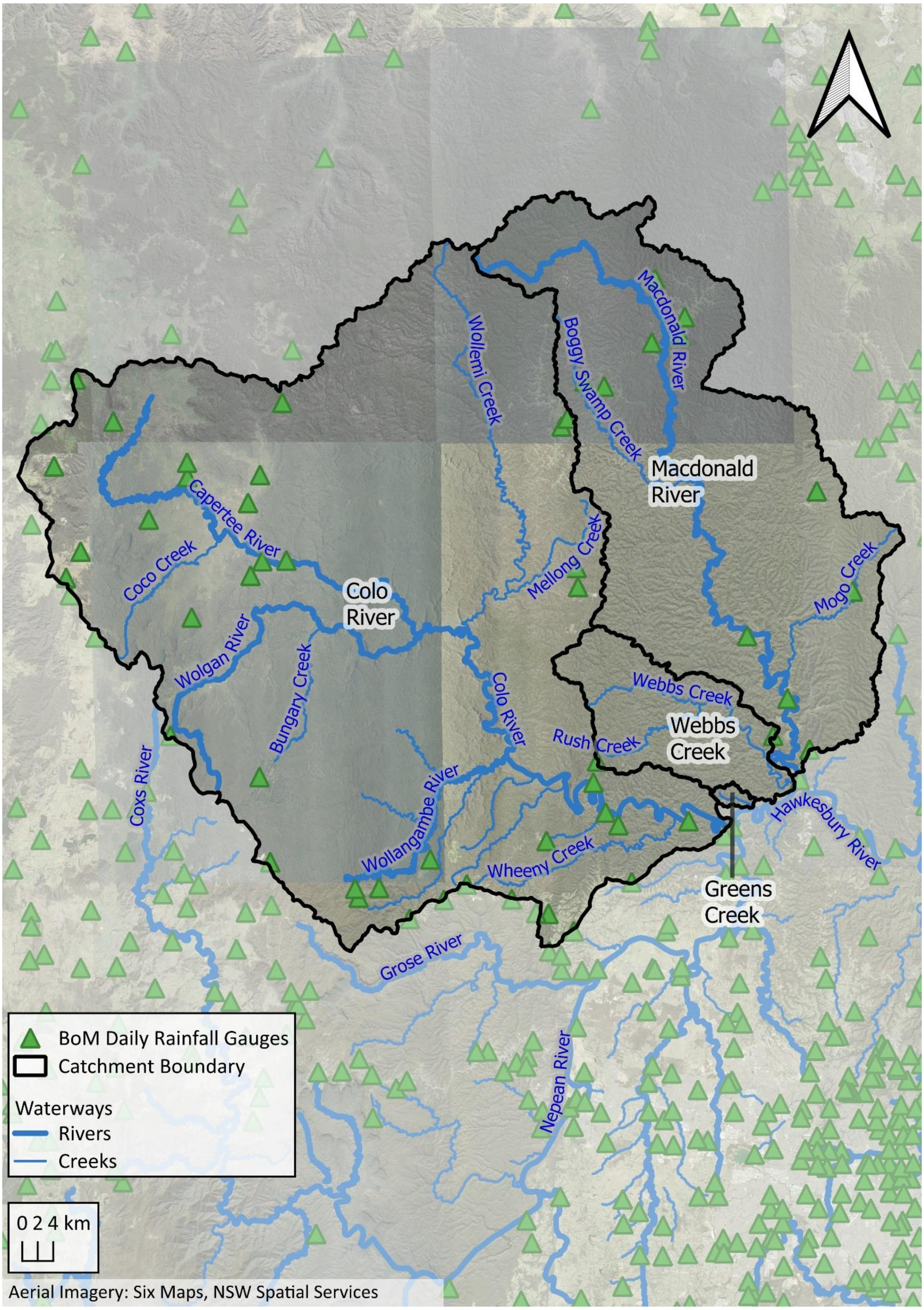

Figure 3-1 BoM daily rainfall gauges

3.3.2 Streamflow Data

Streamflow estimates are derived through a combination of recorded water levels at a location, and a rating curve that allows for the conversion of these water levels into a discharge estimate. Rating curves are derived from field measurements that are undertaken at the gauging location, estimating flows (also referred to as discharge) using current meters.

A key challenge for the derivation of rating curves is during high flows. These can be limited in terms of the ability to measure the flows at these higher flood events (together with these events being less frequent). This can lead to higher uncertainty for larger flow events. It is therefore important to ensure that gauges that are used for flow estimation have been "rated" at higher flow events to ensure that they are representative for flood events. Where they have not been rated, then alternative approaches, such as the use of hydraulic models, can be used to estimate an extrapolated the rating.

Figure 3-2 shows the locations of gauges within the study area. **Table 3-3** summarises the gauge operational information and whether they were operational during possible calibration events. **Table 3-4** summarises the maximum gauging and ratings for the key gauges in the study area from the gauge owner. Given uncertainties regarding the rating curves for the gauges relevant to the current study (Upper Colo and St Albans gauges), a rating curve review was conducted and this is reported in **Section 3.3.3**.

In addition to streamflow estimates, there are also several water level only gauges along the Hawkesbury River that may be used for setting downstream tail water conditions during the calibration and validation stage of the portion of the study (**Section 5.3).**

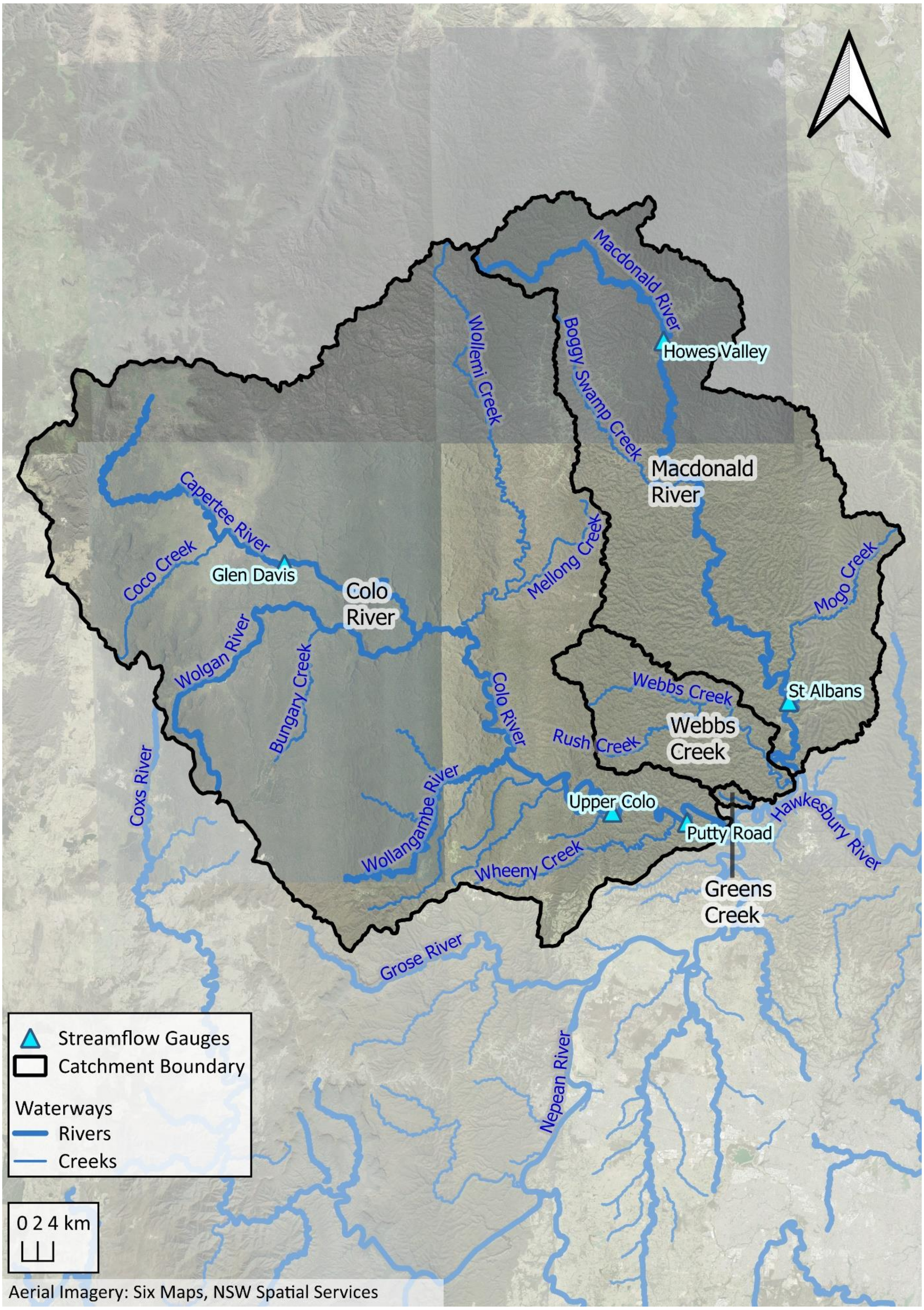

Figure 3-2 Flood gauges in the catchments

Table 3-3 Streamflow gauges within the catchment

Gauge ID (WaterNSW and Sydney Water or MHL)	Mar 1978	Aug 1986	Apr/ May 1988	Aug 1990	Aug 1998	Feb 2020	Mar 2022	July 2022
212290 / 563033; Upper Colo (Colo River)	✓	✓	✓	✓	✓	✓	✓	✓
212018 / NA; **Glen Davis (Capertee River)**	✓	✓	-	✓	✓	✓	✓	✓
212908 / NA; Putty Road (Colo River)[1]							✓	✓
212021 / 561036; Howes Valley (Macdonald River)	✓	✓	✓	✓	-	-	✓	✓
212228 / 061353; St Albans (Macdonald River)	✓	-	-	✓	✓	✓	✓	✓

[1] **The Putty Road gauge is manually operated and may not be useful for validation and calibration**

Table 3-4 Streamflow gauges – rating and gauging

ID	Gauge Name	Key Tributary	Max Rating	Max Gauging	Comments
212290	Upper Colo Station – Colo River	Colo River	19.20m; 5681 m^3/s [3830 m^3/s according to AWACS]	19.18m; 3824 m^3/s in March 1978	The 2019 Regional Flood Study notes that it malfunctioned during the 1986 flood event. It is noted that AWACS (1997) revised the rating curve for this gauge for higher flow events.
212018	Glen Davis – Capertee River	Capertee River	5.27m; 202.5 m^3/s	4.26m; 202.5 m^3/s in June 1978	The Capertee River at Glen Davis gauge is on an unstable sand bar and is subject to change during flood events.
212228	St Albans – Macdonald River	Macdonald River	7.00m; 766.2 m^3/s	5.91m; 510.4 m^3/s in March 1978	The Macdonald River at St Albans is sandy and subject to morphological changes. The dynamic nature of the Macdonald River may reduce the confidence in the gauge.
212021	Howes Valley – Macdonald River	Macdonald River	6.87m; 691 m^3/s	2.99m; 163.2 m^3/s in March 1978	This gauge is relatively high up in the catchment.

3.3.3 Rating Curve Data Review

A review of the rating curves at the Upper Colo Gauge on the Colo River and the St Albans Bridge Gauge on the Macdonald River was undertaken.

AWACS (1997) reviewed the rating curve at the Colo River at Upper Colo gauge. This review identified that for higher levels, the WaterNSW rating over-estimated the flows. AWACS (1997) therefore developed a revised rating curve for the gauge. The Upper Colo Gauge was also reviewed as part of the Hawkesbury-Nepean River Flood Study (Rhelm CSS 2024) based on a Mannings calculation and WaterNSW surveyed cross section of the channel. Rhelm CSS (2024) found the AWACS (1997) curve better matched the Mannings calculated curve than the WaterNSW rating. As a result, the AWACS (1997) curve was adopted for the Hawkesbury-Nepean River Flood Study.

For this study, a further review was undertaken using the TUFLOW hydraulic model. The TUFLOW rating was based on the stage-discharge relationship for the rising limb of the calibration and validation events (See **Section 5.3).** This approach minimised the effect of hysteresis to provide more confidence in the rating.

The Colo River at Upper Colo gauge and Macdonald River at St Albans gauge were assessed using the calibration models to compare the water level and flow across both gauges. Surveyed cross sections were collected at each gauge location to provide a greater level of confidence in the modelled stage-discharge relationship estimated from the model.

The Upper Colo rating curve review summary is provided in **Figure 3-3**. The review suggests a close alignment with the curve adopted by AWACS (1997). As a result of this finding, the AWACS (1997) rating curve was adopted by the current study for flow conversions between water level and flow at the Upper Colo water level gauge.

It is noted that there is uncertainty regarding the validity of the WaterNSW gauge zero relative to the Australian Height Datum. The survey cross-section collected at this location as a part of this study suggested that the bed level at the gauge was around 3.1 mAHD while the WaterNSW gauge zero level is around 1.47 mAHD. Through correspondence with WaterNSW, it was revealed that there is some uncertainty with the datum used for the WaterNSW cross section datum. It was considered that, for this analysis, the gauge zero level be increased by 1.5 m to better align with the survey in from this study. However, the calibration of the Colo River is based on the WaterNSW gauge zero level as there remains some uncertainty regarding the datum, cross section history and gauge location history. The hydraulic model calibration is discussed further in **Section 5.3.**

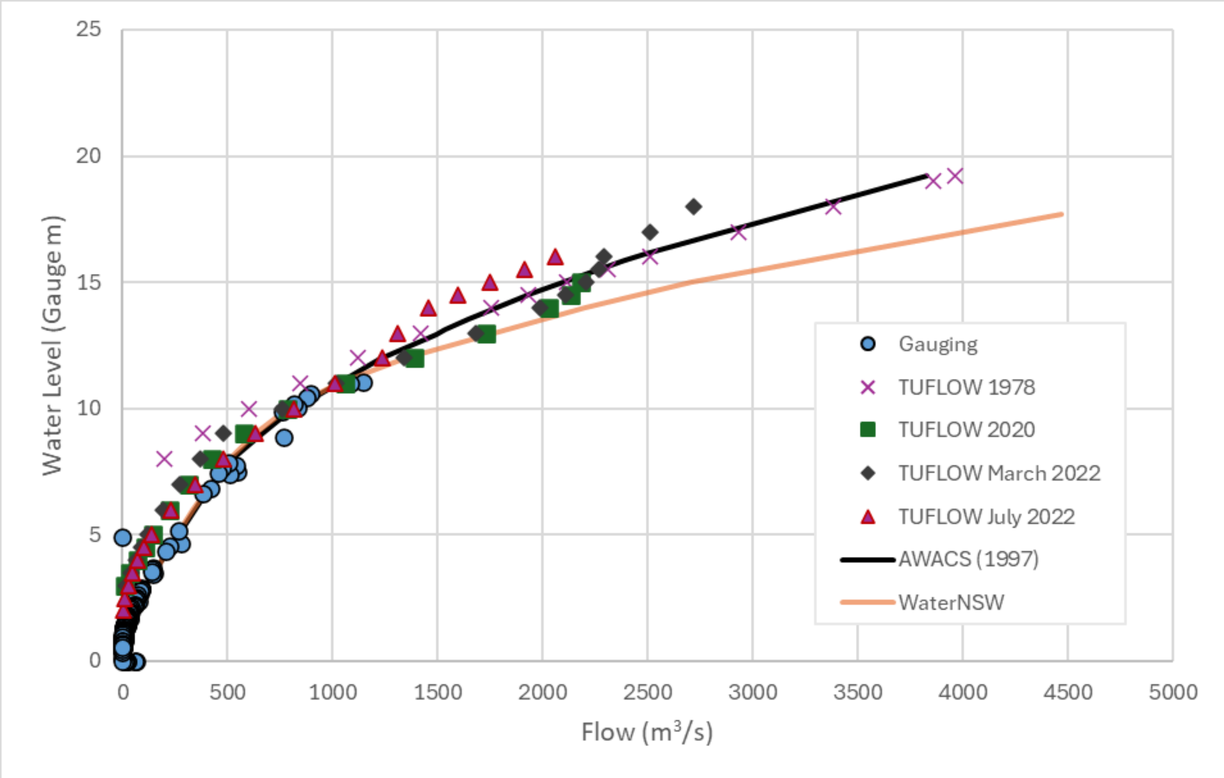

Figure 3-3 Colo River at Upper Colo Gauge rating curve review summary

For the St Albans gauge, the rating curve review is shown in **Figure 3-4**. The TUFLOW rating was based on the stage-discharge relationship for the rising limb of the calibration and validation events (See **Section 5.3).** This approach minimised the effect of hysteresis to provide more confidence in the rating. Each modelled stage-discharge relationship for each event was very similar and provides confidence in the rating adopted for this study. The WaterNSW rating shows higher flows at lower levels compared to the TUFLOW ratings. Given the close alignment of the TUFLOW rating, that is informed by 2D modelling and recent survey, this study has adopted a rating curve based on the TUFLOW results.

There is some potential uncertainty for this rating for larger events. As identified in Rhelm CSS (2024), for large Hawkesbury River flood events, there is a potential for some backwater effects which would influence the rating curve.

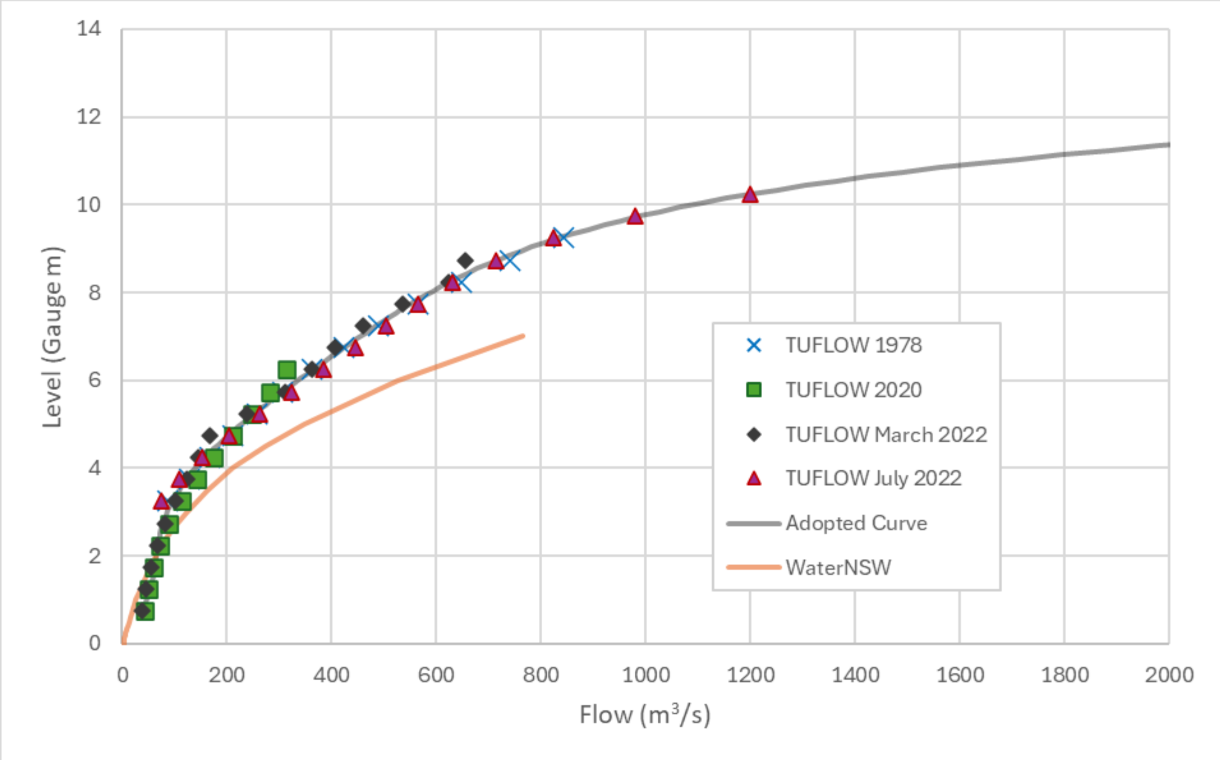

Figure 3-4 Macdonald River at St Albans Gauge rating curve review summary

3.4 Spatial Data

The following spatial data was provided by Council in shapefile and geodatabase format:

- building footprints captured from 1998 and 2016;
- cadastral boundaries;
- bridges and speedhumps;
- easements;
- land zoning;
- PMF and 1% AEP flood extents from historic studies;
- Council assets including bridges, culverts and roads;
- HLEP (2012) Land zoning; and
- Vegetation mapping (2018).

The 1% AEP and PMF flood extents provided are based on the:

- Macdonald River Flood Study (2004)
- 1978 Flood Extent for the Colo River; and
- Lower Hawkesbury Flood Study (AWACS, 1997)

3.5 Aerial Photography

Aerial photography from the following sources was used for this assessment:

- NSW SixMaps (https://maps.six.nsw.gov.au/); and

- Nearmap (https://www.nearmap.com/au/en).

The higher definition Nearmap was used where available, however Nearmap images do not cover the entire study area.

3.6 Local Policies and Emergency Management Plans

A variety of relevant planning documents, where available, were also reviewed and considered as part of the study. These documents are listed in **Table 3-5**.

Table 3-5 Local policies and plans

Document	Relevance to Study
Hawkesbury City Council Flood Policy (2020)	The flood policy sets out the controls for flood planning. Controls relate to flood function and flood hazard and are designed to apply a risk based approach to floodplain management. The Policy includes specific controls for new development, and for additions, alterations, intensification or redevelopment of existing uses. The existing policy excludes freeboard from the flood planning level. Typically, flood planning levels in NSW include a freeboard of 0.5m for mainstream flooding. This FRMS makes recommendations for a future flood related DCP chapter that will supersede the Flood Policy.
Hawkesbury City Council Local Environmental Plan 2012 (HLP 2012)	The LEP's existing flood related planning controls have been reviewed within the context of flood risk and planning within the study area (**Section 4**).
Hawkesbury City Council HDCP 2002)	The DCP's existing flood related planning controls have been reviewed within the context of flood risk and planning within the study area (**Section 4**).
Hawkesbury Nepean Valley Flood Emergency Plan (SES, 2020)	Special arrangements described in the Hawkesbury-Nepean Valley Flood Emergency Plan cover prevention and preparedness measures, the conduct of flood operations and the transition to recovery for floods in the Hawkesbury-Nepean Valley. The Plan covers the Colo River, Webbs Creek, Macdonald Rivers. Greens Creek is not mentioned in the Plan however evacuation is considered within the Webbs Creek and Colo Sectors, including the inundation of Greens Road. This study informs the flood classification within the study area and provide further information on the depth, timing and duration of flooding to inform future revisions of the HNFESP.

3.7 Guideline and Reference Documents

3.7.1 Australian Rainfall and Runoff

Australian Rainfall and Runoff is a national guidance document, originally published by The Institution of Engineers, Australia (e.g. 1987 Edition, Pilgrim (Ed)) and currently published by the Australian Government (through Geoscience Australia, Ball et al, 2019). The document has been used extensively as the basis for design flood estimation for flood studies.

The 2019 version of the document (Ball et al, 2019) provides a significant revision of the 1987 version and incorporated additional information such as:

- Updated intensity-frequency-duration IFD relationships (using rainfall data collected since the analysis for the 1987 version was conducted);
- Updated storm temporal patterns;
- Advice on blockage for structures such as culverts and bridges (not discussed in the 1987 version);
- Advice on climate change adjustments associated with emission-related projections; and
- Some of the specific parameters associated with the guideline are provided through the ARR Data Hub (http://data.arr-software.org/).

OEH (now DCCEEW) in January 2019 published a guidance on incorporating the updated Australian Rainfall and Runoff into flood studies in NSW. The Flood Risk Management Guide: Incorporating 2016 Australian Rainfall and Runoff in studies (OEH, 2019) is a key document in guiding the application of Australian Rainfall and Runoff. In particular, there is specific guidance related to rainfall losses that is of particular relevance to this assessment. For design flood modelling, the OEH guideline recommends the use of the mean temporal pattern within the 10 ensemble storms.

3.7.2 NSW Flood Risk Management Manual

DCCEEW is the custodian of the NSW Government's Flood Risk Management Manual (2023a), which is the key guiding document in the management of flood-prone land.

In addition to the Flood Risk Management Manual (NSW Government, 2023a), DCCEEW have issued a toolkit to support policy implementation. The manual replaces the Floodplain Development Manual (NSW Government, 2005) and provides guidelines covering a diverse range of topics including:

- Understanding flood behaviour;
- Assessing flood damage;
- Climate change;
- Other flood management concerns; and
- Supporting emergency management.

The guidelines can be found at http://www.environment.nsw.gov.au/topics/water/floodplains/floodplain-guidelines.

3.8 Site Inspection

A site inspection of the study area was undertaken by Rhelm and Catchment Simulation Solutions (CSS)) staff on 17 and 18 February 2022. On 17 February, the temperature was 35 degrees and there were evening storms in the area. On 18 February, the temperature was 32 degrees. The catchments had recorded 30-40 mm of rainfall in the proceeding 7 days. Flows were near average in the Colo and Macdonald Rivers at the time of the inspection.

Key locations inspected were:

- Colo River (17 February 2022)
  - Upper Colo bridge
  - Colo RFS Shed
  - Sumerset Outdoor Learning Centre
  - Bielany Camp Site
  - Wheeny Creek/Colo River Confluence
  - Putty Road Bridge

    - Greens Road Bridge – Lower Portland
    - Colo River/Hawkesbury River Confluence
- Greens Creek (17 February 2022)
    - Greens Creek at Greens Road
- Webbs Creek (17 February 2022)
    - Webbs Creek/Hawkesbury River Confluence
    - Chaseling Road N Bridge
    - Webbs Creek Road to DinkiDell Campsite
- MacDonald River (18 February 2022)
    - MacDonald River Village
    - MacDonald River/Wrights Creek Confluence
    - St Albans Bridge
    - St Albans RFS Station
    - St Albans Common – Mogo Creek
    - Macdonald River at Upper Macdonald
    - Macdonald River at Higher Macdonald

The site inspection provided an overview of the study area and an appreciation of key features affecting flood behaviour and evacuation constraints. Photographs of the site inspection are provided in **Appendix B**.

4 Hydrologic Model

Two computer models were developed to simulate flood behaviour across each of the four catchments:

- A hydrologic model was developed to simulate the transformation of rainfall into runoff across the catchment. The hydrologic model was developed using the WBNM software, and,
- A hydraulic model was developed to simulate how the runoff from the hydrologic model would be distributed/move across the catchment. The hydraulic model was developed using the TUFLOW software.

This section details the hydrologic model build, calibration and design event modelling, while Section 5 describes the hydraulic model

4.1 Model Development

The hydrological modelling was completed using the WBNM (Watershed Bounded Network Model) hydrological model (v2017_001c), and is based on the model that was developed for the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024).

WBNM calculates runoff based on rainfall hyetographs. By dividing the catchment into sub-catchments, WBNM allows for the generation of hydrographs at various locations within the catchment, effectively modelling the spatial variability of rainfall and its associated losses. The model distinguishes between overland flow routing and channel routing, and can be applied in rural and urban catchments. The subcatchment delineation has been adapted from the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024) and is based on available LiDAR information, with some updates undertaken in this study to align with the hydraulic modelling. The total subcatchments are shown in **Table 4-1**, and the subcatchment delineation is shown in **Figure 4-1**.

Details of the inputs and data sources common to each catchment are summarised in **Table 4-2**.

Table 4-1 Number of subcatchments for each catchment

Catchment	Number of Subcatchments
Colo River	252
Macdonald River	107
Greens Creek	5
Webbs Creek	19

Table 4-2 Hydrological model input data

Parameter	Data Source
Percentage impervious	Percentage impervious areas are largely a factor of development intensity. These areas can be quantified by rasterising point land-use classification data from LiDAR. This processing was completed for the Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024) and has been drawn upon for this study. Note that the impervious area percentage is very low as the catchments are largely undeveloped, and therefore this is not a significant parameter for this study.

Parameter	Data Source
Runoff routing	Routing refers to the transfer of flows from one subcatchment to another. WBNM manages this runoff through the catchment lag factor (model parameter, 'C'). The Hawkesbury-Nepean River Flood Study (Rhelm CSS, 2024) and the historical calibration process informed the selection of the 'C' parameter. A 'C' parameter of 1.55 was adopted for the Colo River catchment, and 1.9 was adopted for the Macdonald River and Webbs Creek catchments. Given catchment similarities, a 'C' parameter of 1.9 was adopted for Greens Creek. The impervious lag factor was set using the recommended value of 0.1
Rainfall losses	Under the new methodology set out in ARR2019, rainfall parameters for hydrological modelling are all available from the ARR Data Hub and should be adjusted per NSW government guidance (Incorporating 2016 Australian Rainfall and Runoff in Studies). Deviation from this approach is expected when better site-specific information is available. In the case of the Colo River and Macdonald River catchments, the data from the Hawkesbury-Nepean River Flood Study (2024) provided the most up to date information and supplemented available data from the ARR Data Hub. For the historical calibration events in the Colo and Macdonald River catchments, the Hawkesbury-Nepean River Flood Study (2024) values formed the starting point for the calibration process, though adjustments were made for individual historical events, as discussed below in **Section 4.2.** The design rainfall losses for the Colo and Macdonald River catchments differed from the historical event losses as a consequence of the Flood Frequency Analyses (FFA) that was undertaken. The FFA is discussed in **Section 4.3.** More information on the design event modelling process is found in **Section 4.4.** For the design rainfall losses in the Greens and Webbs Creek catchments, probability neutral burst losses from ARR Data Hub were adopted for the initial loss, while the continuing losses followed the values adopted for the Macdonald River catchment due to similar catchment conditions. For more design model information, refer to **Section 4.4.**
Rainfall intensities and hyetographs/ temporal patterns	Historical rainfall intensities and hyetographs were sourced from available rainfall gauge data (refer to **Section 3.3.1**). Design rainfall intensities and temporal patterns were taken from the ARR Data Hub and are discussed in **Section 4.4**. The intensities and temporal patterns for Probable Maximum Precipitation (PMP) modelling were dictated by the Generalised Southeast Australia Method (Colo, Macdonald and Webbs catchments) and Generalised Short Duration Method (Webbs and Greens catchments) approaches, as discussed in **Section 4.4**.
Areal reduction factors	The areal reduction factors for design rainfall modelling were taken from the ARR Data Hub and were varied for each model based on the relevant catchment area. See **Section 4.4** for more details.
Stream lag	The stream lag factor, 'F', is a WBNM-specific parameter that accounts for variation in flow velocity and lag times caused by stream channel roughness. As the four catchments are all natural catchments, the WBNM-recommended value of 1 (Boyd et al, 2017) was adopted for all subcatchments in the model.

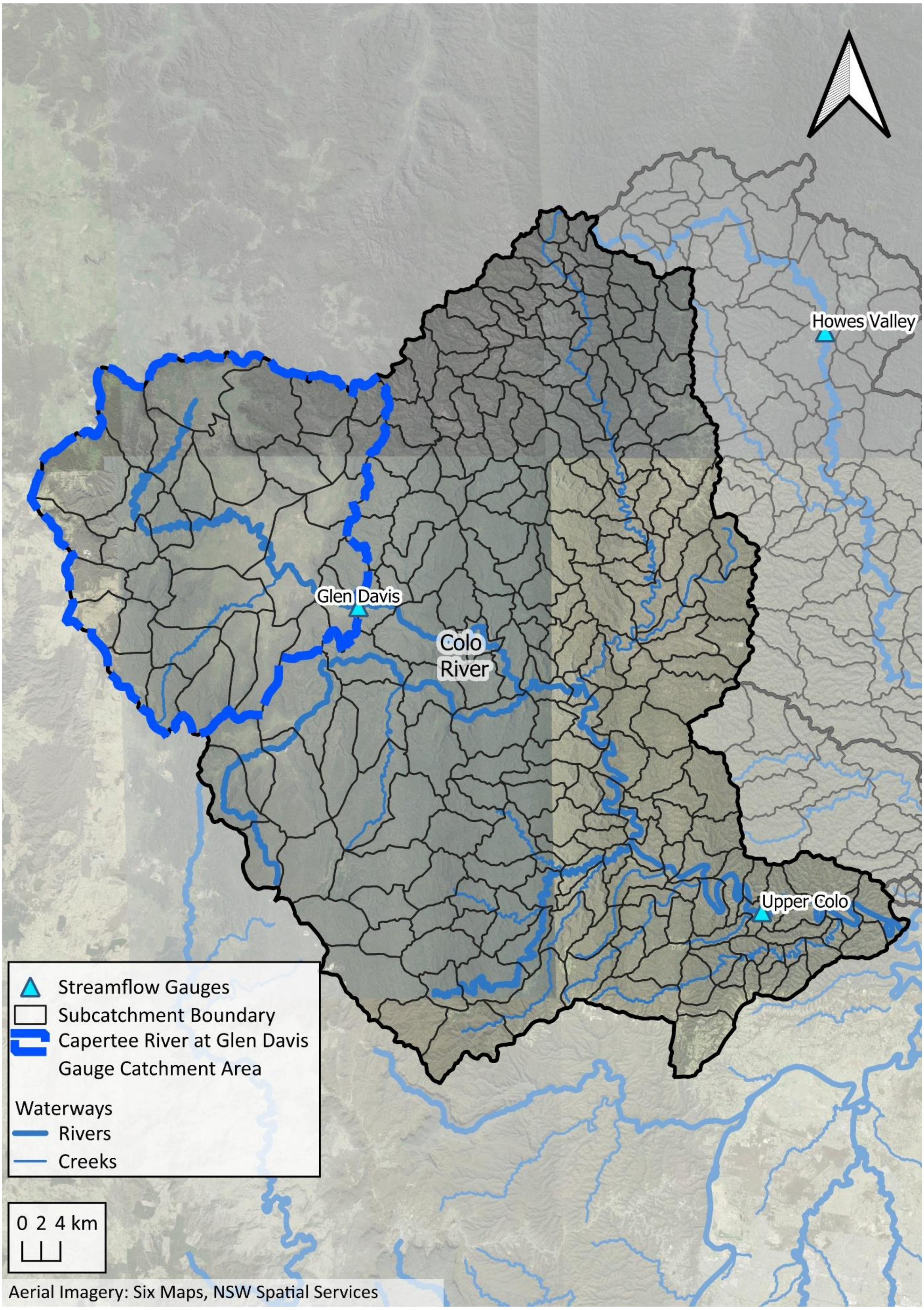

Figure 4-1 Subcatchment delineation for hydrological model

4.2 Calibration and Validation

Calibration of a hydrological model is important, as it ensures that model parameters are appropriate for a catchment. Four water level gauges were identified for the calibration of the hydrological model. These gauges provide useful historical snapshots for calibration of the Colo and Macdonald River catchments.

The Colo and Macdonald River hydrological models were calibrated to four historical flood events, namely:

- July 2022
- March 2022
- February 2020
- March 1978

Following a Flood Frequency Analysis (FFA) undertaken at the Upper Colo and St Albans gauges (refer to **Section 4.3.1** and **Section 4.3.2** respectively), the estimated AEP of the calibrated events is shown in **Table 4-3**.

Table 4-3 Estimated AEPs of historical calibration events

	Estimated AEP (1 in X Years)			
Catchment	March 1978	February 2020	March 2022	July 2022
Colo River	~80	10 – 20	30 – 40	10 – 20
Macdonald River	~20	2 – 5	10 – 20	~20

While accounts of larger floods with higher water levels exist, there is a lack of spatial and temporal rainfall data available for these events (e.g. the 1889 flood event in the Colo River). The selected calibration events include the 1978 flood, which was the largest flood event that occurred at the Upper Colo since gauge records started and the July 2022 event, which was the largest event that occurred at St Albans for the available gauge record.

To calibrate a model, consideration of the underlying historical data and model parameters is required. From the calibration process undertaken in the Hawkesbury-Nepean River Flood Study (2024), the processed historical data and catchment lag parameters were found to be reasonable for this study. Given the Hawkesbury-Nepean River Flood Study (2024) was primarily focussed on the flood behaviour of the Hawkesbury-Nepean River, fine-tuning of rainfall losses was undertaken to enhance the calibration outcomes for the Colo and Macdonald River catchments.

The calibration inputs and comparison with the gauge records are provided for the above events in the following sections.

4.2.1 Colo River Calibration

4.2.1.1 Catchment Context

The Colo River Catchment upstream of the Upper Colo gauge has a catchment area of around 4340km^2. A large majority of the catchment falls within national parks, with steep terrain and gorges.

There are two streamflow gauges in this catchment, Glen Davis and Upper Colo. The gauge locations are shown in **Figure 4-2.** The Glen Davis gauge is located in the upper portion of the catchment. The catchment characteristics upstream of the gauge is different to the majority of the catchment, with largely rural areas around the Glen Davis area draining to this point. The WaterNSW site report identifies that the river at this location is unstable, with a sand bar. The flow ratings (are also only up to 4.26m on the gauge, or approximately 80m^3/s. The flows at the Capertee River gauge at Glen Davis were particularly difficult to reproduce using the model. In each calibration event, this particular area received relatively low rainfall compared with the remainder of the Colo River catchment. There are also very few sub-daily rainfall gauges in this part of the catchment, making representation of the rainfall pattern across this catchment challenging. With a catchment area of 1030km^2, there are only three or four sub-daily rainfall gauges at most (see example in **Figure 4-4**).

The Upper Colo River gauge is located approximately 30 kilometres upstream from the Colo and Hawkesbury River's junction. This gauge has a long record, with peak levels recorded back to 1909 and continuous records since the 1960s (although 1964 has limited recorded data).

The Upper Colo gauge is located in a reasonably confined valley. However, BoM (2018) notes that this gauge has complex floodplain dynamics, due to the presence of backwater areas/ billabongs which lie within the floodplain. This may increase the overall storage in the area. This would have the potential to influence the falling limb of the hydrograph in particular.

Testing of the rainfall losses at this location suggested that the flow estimates were very sensitive to rainfall loss adopted, although this is reflective of the low rainfalls.

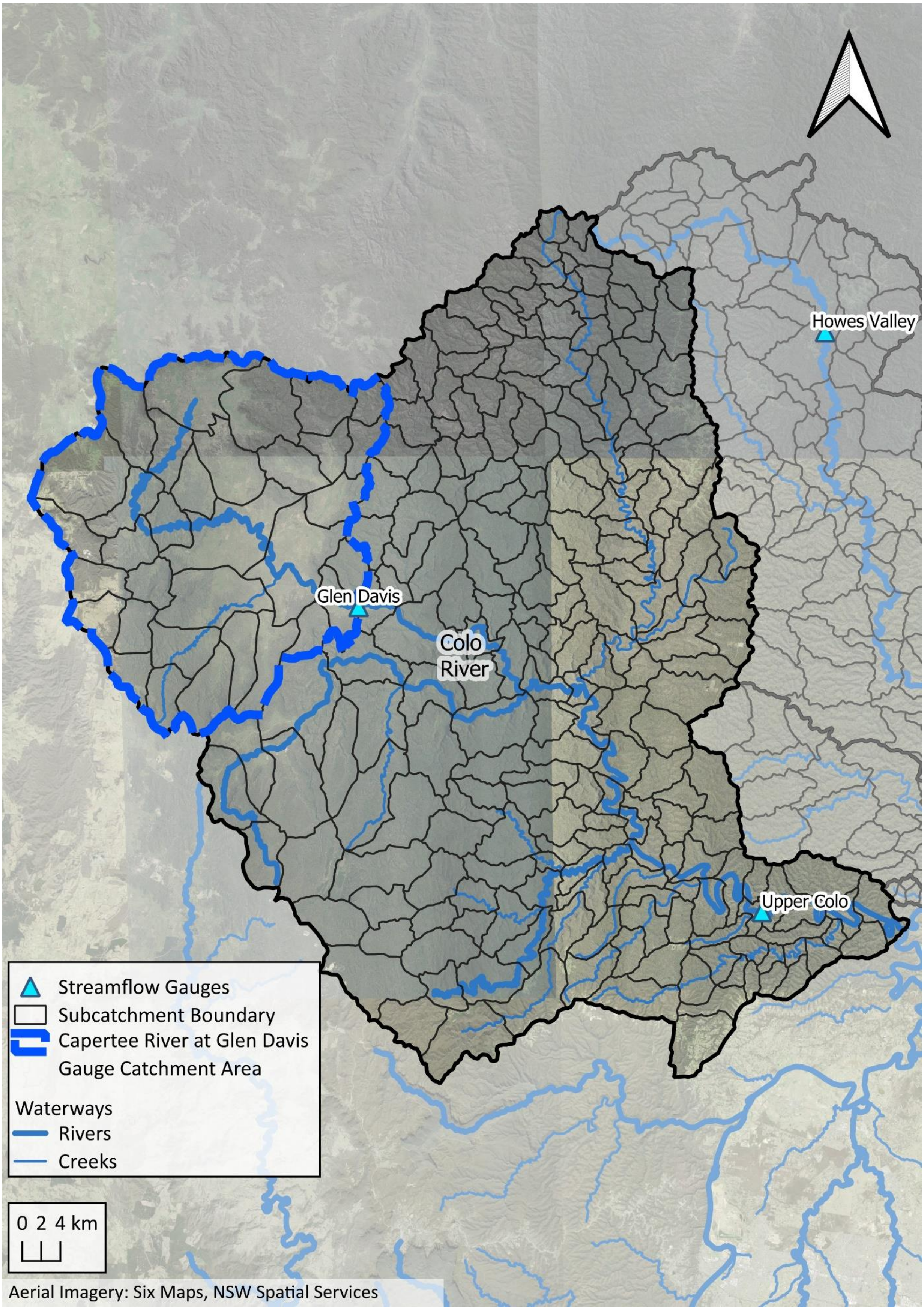

Figure 4-2 Colo River streamflow gauges and Glen Davis Gauge catchment area

4.2.1.2 Rainfall Losses

The refinement of rainfall losses was undertaken to update the hydrological model calibration for the Colo River catchment. Initial and continuing loss combinations for the historical events were originally based on calibration losses used in the Hawkesbury-Nepean River Flood Study (2024). An iterative process which involved the testing of various initial and continuing loss combinations was undertaken to improve the match to historical streamflow gauge data. The result of this process found that the losses used in the Hawkesbury-Nepean River Flood Study (2024) provided a reasonable representation of the catchment behaviour for three out of four historical events, with modifications required for the July 2022 event. For the July 2022 event, the Colo River continuing loss was changed from 0.35mm/hr to 0.8mm/hr to better match the recorded flows.

The adopted rainfall losses can be found in **Table 4-4**. These losses are substantially greater than the probability neutral burst losses from ARR Data Hub. For reference, the 5% AEP 72 hr probability neutral burst loss was 46.8 mm for the Colo River. The ARR Data Hub losses were checked and found to be too low to provide a suitable match for the hydrological calibration. The large difference in initial losses may be attributed to the long duration of the modelled rainfall events and antecedent moisture conditions associated with the calibration and validation events.

Table 4-4 Colo hydrological calibration model rainfall losses

Catchment	Representative Gauge	1978		2020		March 2022		July 2022	
		IL	CL	IL	CL	IL	CL	IL	CL
Capertee River	Glen Davis	140	4.8	110	2	45	5.5	55	0.6
Colo River	Upper Colo	110	2.1	170	3.1	90	0.9	80	0.8

IL = Initial Loss (mm), CL = Continuing Loss (mm/hr)

4.2.1.3 Parameters

The adopted hydrological calibration model inputs for the Colo River catchment are shown in **Table 4-5**.

Table 4-5 Colo River hydrological calibration model parameters

Parameter	Calibration Input
Rainfall Spatial Distribution	A total event rainfall isohyet map was prepared for each event based on the processed pluviograph and daily rainfall data from the Hawkesbury-Nepean River Flood Study (2024). The isohyets and rainfall gauges used for each historical event are shown in **Figure 4-3** to **Figure 4-6**.
Temporal Pattern	The temporal pattern applied to a subcatchment in the model was derived from the nearest pluviograph station. The stations used for each of the historical events are shown in in **Figure 4-3** to **Figure 4-6**.
Runoff Routing (WBNM 'C' Parameter)	A 'C' parameter of 1.55 was adopted for each calibration event, in line with the Hawkesbury-Nepean River Flood Study (2024).

Parameter	Calibration Input
Rainfall losses	Following an iterative process, variable rainfall losses were adopted across each calibration event. With the variance in catchment conditions between the Capertee River and Colo River, adopted rainfall losses differed between the Capertee River catchment and the remainder of the Colo River catchment. A summary of the rainfall losses adopted for each calibration event is shown in **Table 4-4**.

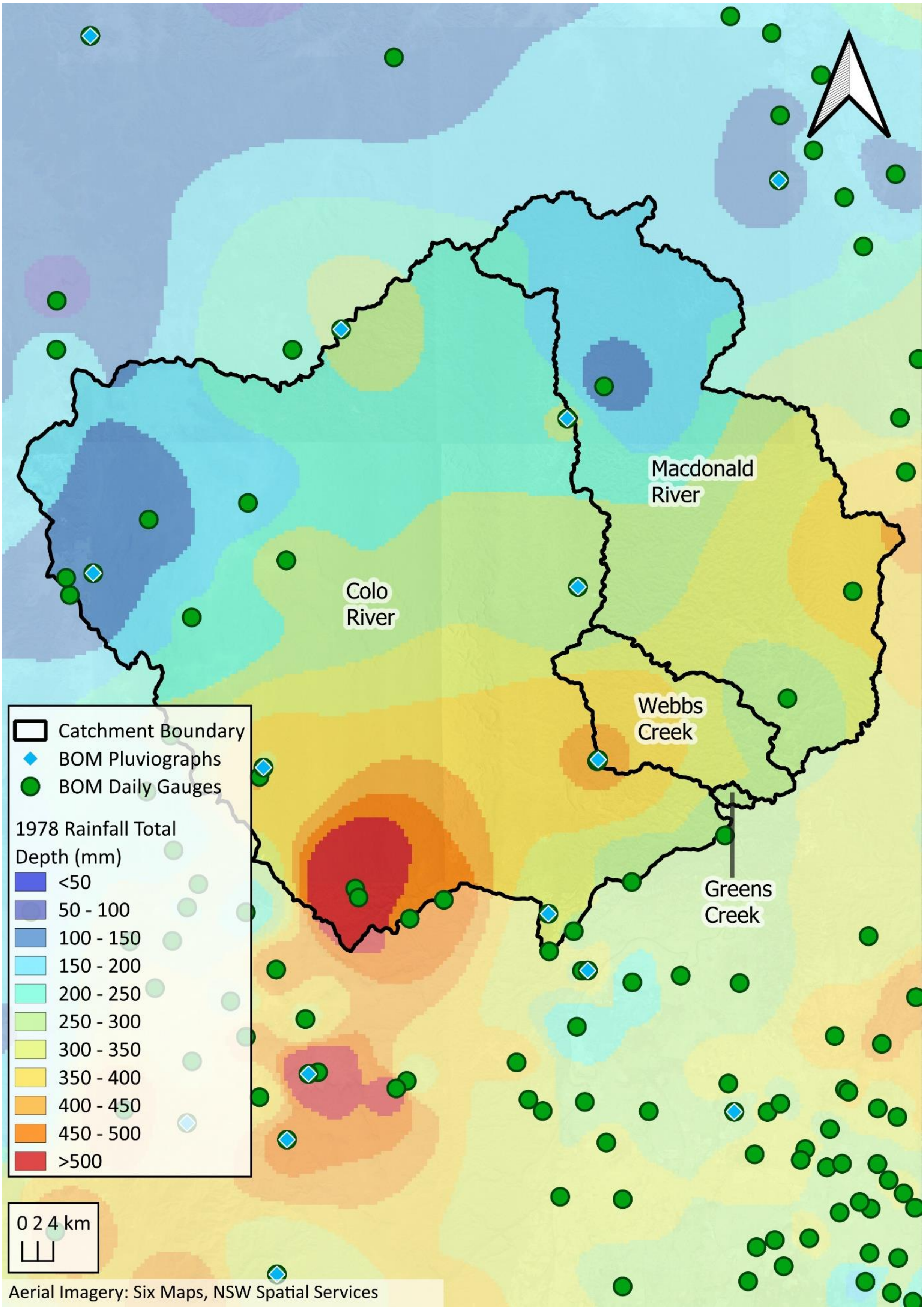

Figure 4-3 1978 event rainfall isohyet and available gauges

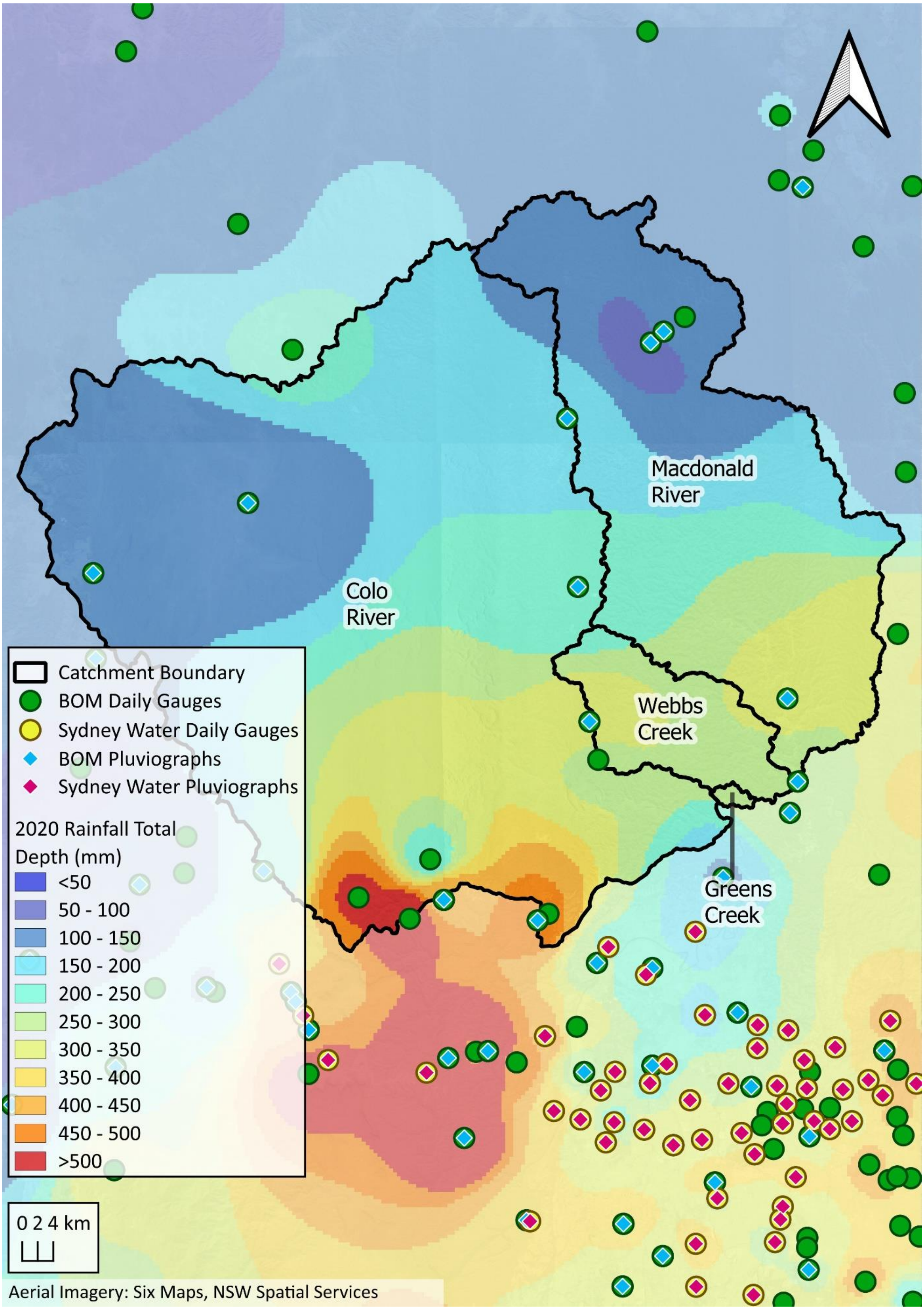

Figure 4-4 2020 event rainfall isohyet and available gauges

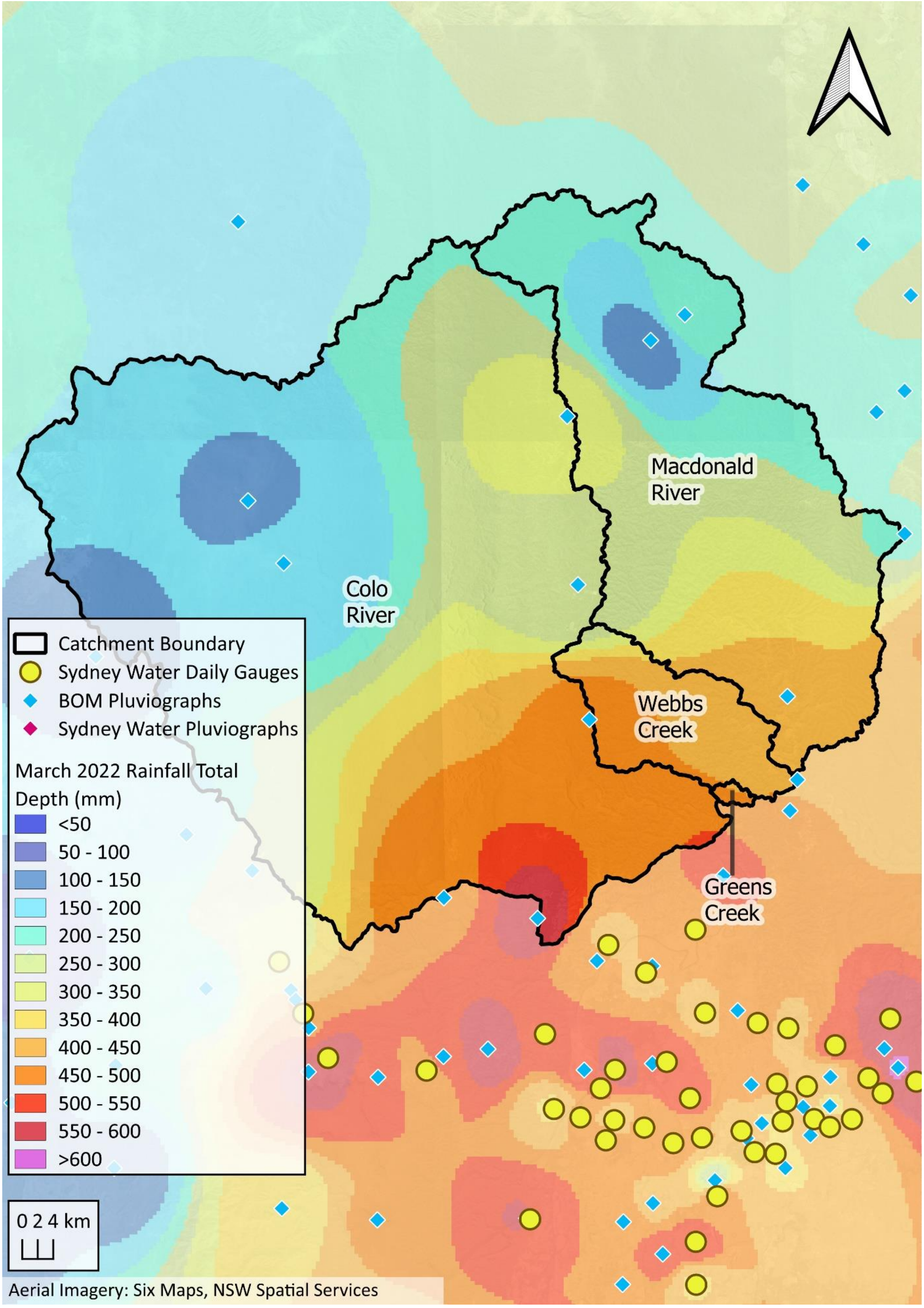

Figure 4-5 March 2022 event rainfall isohyet and available gauges

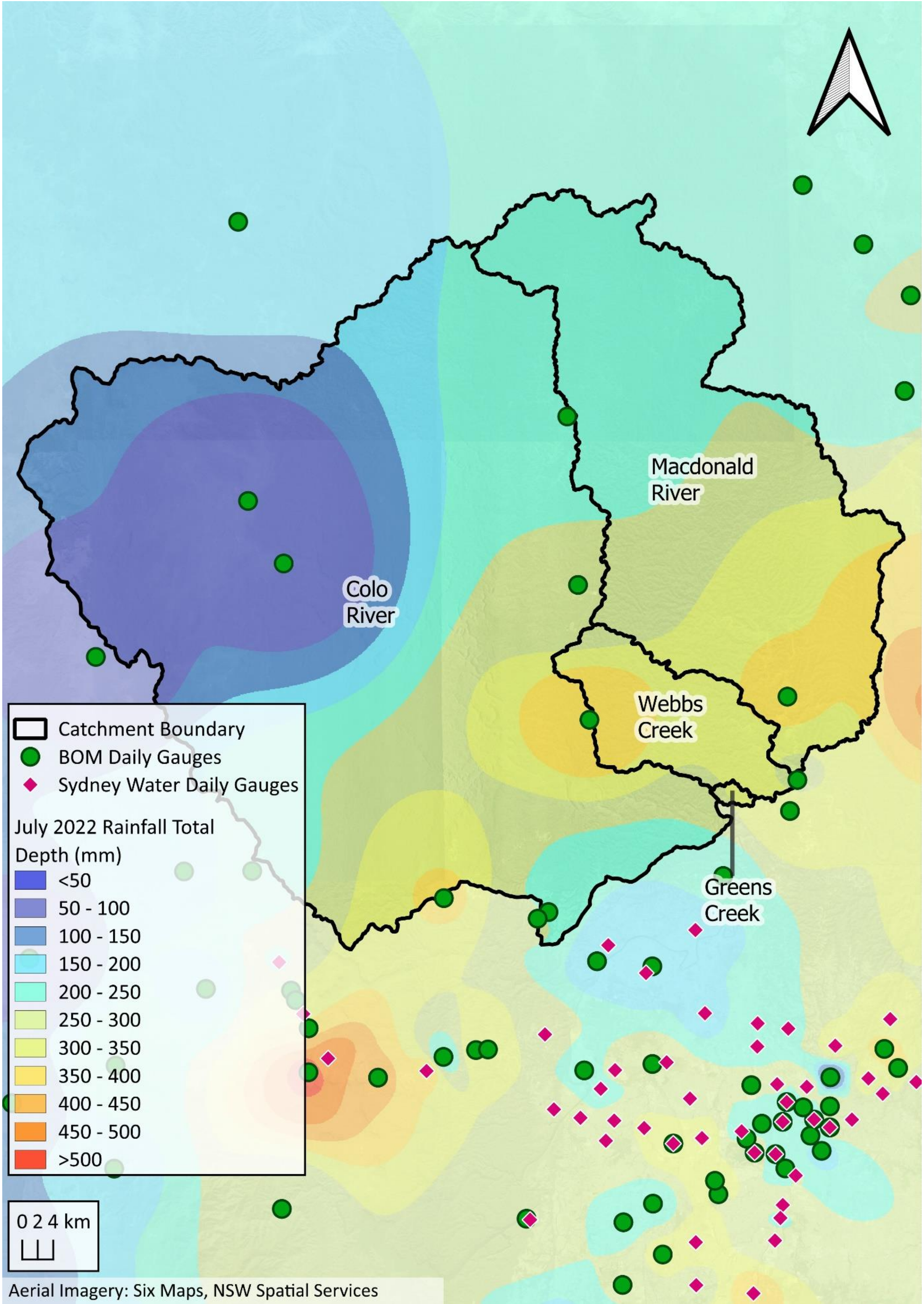

Figure 4-6 July 2022 event rainfall isohyet and available gauges